Codes and Standards Enhancement Initiative For PY2004: Title 20 Standards Development

Analysis of Standards Options For Central Furnace Air Handlers

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Table of Contents

1 Introduction 1
2 Product Description 1
3 Market Status 2
3.1 Market Penetration 2
3.2 Sales Volume 2
3.3 Market Penetration of High Efficiency Options 2
4 Savings Potential 2
4.1 Baseline Energy Use 2
4.2 Proposed Test Method 3
4.3 Efficiency Measures 3
4.4 Standards Options 4
4.5 Energy Savings 6
5 Economic Analysis 7
5.1 Incremental Cost 7
5.2 Design Life 7
5.3 Life Cycle cost 7
6 Acceptance Issues 8
6.1 Infrastructure Issues 8
6.2 Existing Standards 8
7 Recommendations 9
8 References 10
9 Appendix A 13

1 Introduction

The Pacific Gas and Electric Company (PG&E) Codes and Standards Enhancement (CASE) Initiative Project seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (CEC) and other stakeholders in the development of these new and updated standards. The objective of this project is to develop CASE Reports that provide comprehensive technical, economic, market, and infrastructure information on each of the potential appliance standards. This CASE report covers standards and options for residential air handler fans.

2 Product Description

This Codes and Standards Enhancement Initiative (CASE) study analyzes the air handler of a residential central furnace, which is defined as *the section of the furnace that includes the fan, motor, filter (usually), and housing, generally upstream of the burners and heat exchanger.* [1] In most California residential applications, the air handler includes an optional cooling coil (EIA 2001). Centrifugal fans are a key component of air handler units in residential split system HVAC equipment. The fan motor typically consumes on the order of 1/10th of the energy (source) that a gas furnace consumes during the heating season.

Forced air cooling requires higher fan airflow than during heating mode since the temperature difference across the evaporator coil is much lower than across the furnace heat exchanger[2]. For example a HVAC system with a 4 ton A/C and a small furnace may operate at 1600 cfm during cooling mode but only 1000 cfm in heating mode. Higher airflow results in lower efficiency in moving air through the duct system, increasing the inefficiency of delivering air to conditioned space. Improvements to air handler fan operating efficiency will yield significant cooling energy savings and peak load reduction benefits. Increasing the efficiency of air handler fans would reduce annual fan energy use, increase heating fuel use slightly to counteract lost motor heat, and reduce cooling energy use. Kendall (2003) estimates that conventional fans use about 15% of the air conditioner electricity; Sachs and Smith (2003) calculate a 250 watt saving with more efficient motors. Including power used by the compressor to remove heat given off by inefficient air handler fans, this is about 325 watts – about 10% of conventional AC electricity use.

Current AFUE (Annual Fuel Utilization Efficiency) test standards to determine furnace seasonal operating efficiencies only address fuel use, and ignore fan electrical impacts. Since the efficiency of the furnace fan is ignored, manufacturers have little incentive to improve motor/fan efficiency. ACEEE estimates 95% of all residential furnace fans use relatively inefficient permanent split capacitor (PSC) motors (Sachs and Smith 2003). The rest use more efficient brushless permanent magnet motors, also known as electronically commutated permanent magnet motors (ECPM). In addition, airflow paths through the air handler cabinets are designed for compactness and heat exchanger efficiency, rather than for optimal airflow.

[1] This analysis makes no recommendations for air handlers for indoor units of heat pumps and similar equipment. For such equipment, the *air handler* is a self-contained cabinet generally including a motor, blower, controls, and heat exchanger, designed to provide heating and/or cooling to a residence. Such units are generally factory-built, and may include auxiliaries such as a filter rack.

[2] The cooling airflow rule-of-thumb assumes 400 cfm airflow/ton cooling capacity, resulting in an approximate temperature difference across the coil of about 28ºF (if 100% sensible load; less if condensing water vapor as well). Gas furnaces typically operate with temperature differences across the heat exchanger of 50 to 70ºF and therefore operate at much lower airflow rates.

Air handler performance is also affected by increased concern over indoor air quality. More effective fan filters (e.g. 2” pleat) can increase the pressure drop through the system by as much as 0.25”w.g., further reducing fan efficiency. In addition, potential ventilation air standards, such as ASHRAE 62.2, combined with the advent of new residential economizer products would contribute to increased fan operating hours. Increased operating hours increases the cost-effectiveness of potential efficiency improvements.

3 Market Status

3.1 Market Penetration

The air handler fan can be part of a furnace, or an air handler section of a heat pump. Table 1 summarizes central system fans for all California households (EIA 2001). It is interesting to note that the stock of heat pumps that provide cooling is supposedly larger than those that provide heating – we suspect one of these figures is in error since the two figures should be the same. Of the 7.4 million California air handler fans, 53% have a cooling coil.

Table 1: California Air Handler Fans

Unit	*Households (millions)*
Cooling	
Central air-conditioner	3.9
Heat pump	0.8
Heating	
Central gas warm-air furnace	5.8
Central electric warm-air furnace	0.9
Central LPG warm-air furnace	0.2
Heat pump	0.6

Source: EIA 1997.

3.2 Sales Volume

Annual California sales are estimated at 350,000 units based on the California fraction of total U.S. households (APPL 2001).

3.3 Market Penetration of High Efficiency Options

Currently ECPM motors are the only high efficiency option being implemented. Data from industry sources indicate approximately 200,000 ECPM motors are sold annually for furnace air handlers (Sachs and Smith 2003). Given that approximately 6,000,000 residential air handlers are sold annually, the national penetration rate among furnaces is at least 3%. Given that approximately 20% of condensing furnaces use ECPM motors, the national market penetration may be as high as 5% (Sachs and Smith 2003). In California, the current market penetration is likely lower than these national figures since ECPM motors are used disproportionately in condensing furnaces, and due to California’s generally mild climate, the market penetration of condensing furnaces is significantly lower than the national average.

4 Savings Potential

4.1 Baseline Energy Use

Research completed by the Canadian Mortgage and Housing Corporation (1992) in the early 1990’s indicated higher fan energy use than previously assumed. ARI 210/240 allows manufacturers to use a default value of 365 Watts per 1000 cfm for SEER certification testing, where the air handler is not part of the air conditioner. More recent field research by Proctor and Parker (Proctor 2000) provides a summary of recent field monitoring and gives a more detailed discussion of the history of residential fan efficiency. In that study, data from nine field tests were analyzed to arrive at an average airflow efficiency of 525 Watts per 1000 cfm, or 44% higher than the 365 Watts per 1000 cfm level assumed in the test standards. For a 10 SEER air conditioner, this would change supply fan energy use from the "expected" 146 Watts/ton to 210 (15% of total system demand). The California Energy Commission has proposed using this latter fan efficacy as a default value for modeling residential HVAC system performance.

Table 2 summarizes several estimates of air handler fan energy use and savings potential. Most of the data sources represent heating only estimates, although the ACEEE reference represents an annual energy estimate. The best California estimate is likely the 290 kWh/year estimate, which is equivalent to a 500 Watt fan operating an average 4.8 hours per day for 120 days. Cooling energy use is estimated at 205 kWh, or 15% of the 1,364 annual kWh consumed for central cooling (PG&E, 1997). While this annual unit energy consumption is fairly low, it is highly concentrated on hot summer days, resulting in high on-peak demands.

Table 2: Estimate of Annual Heating Supply Fan Energy Consumption

Source	Htg/Cooling Use (PSC)	Htg/Cooling Use (ECPM))	Savings (kWh/yr)	Comments
CEC, 2000	290			PG&E area, heating only
CEC, 2002	474-642			Average of models in the CEC furnace database
EIA, 1997	398			RECS-1997
Phillips, B. 1995			180-250 Htg.	Field Study (Heating only savings implied).
Pigg, Scott 2003	800 Htg, 225 Clg.	400 Htg, 155 Clg.	465	Field Study, condensing furnaces only, corrected for gas supplement
Sachs and Smith, 2003	780 Htg.	270 Htg	500 Htg, 200 Clg.	Annual heating and cooling, condensing furnaces

4.2 Proposed Test Method

The ANSI/AMCA 210-99 Standard prescribes a detailed methodology and sensor requirements for conducting laboratory tests on air handler fans to determine airflow rate, pressure, power, and efficiency. This is an appropriate method if airflow measurements are required. Another option, discussed below, is to make use of the various parameters contained in the current DOE test procedure for residential furnaces (DOE 1997).

4.3 Efficiency Measures

DOE has studied the performance of blowers and issued a draft report (DOE, 2002). The efficiency measures that DOE evaluated were improved motor efficiency, blower wheel efficiency, blower geometry, and electrical self-generation (using thermo-electric or similar phenomena). DOE concluded that the most promising option was improving motor efficiency; second best was improved blower wheel efficiency. To achieve maximum benefit, it is important that these measures be optimized in a systems approach so that component sizing and configuration can benefit from improved airflow configurations within the air handler unit, especially as it relates to the entrance and discharge flow paths. Fans are likely to gain efficiency by moving to backwards-curved, air-foil, shaped construction with much tighter gap tolerances. One new product with backward-curved sheet metal blades is a start in this direction (Walker and others 2003). This should give significant efficiency improvements at moderate cost. Phillips (1998) estimated that the change from sheet metal to air foil blades could cut blower power requirements by half, and reduce fan noise levels. Air-foil type blowers have always cost more than traditional forward-curved blowers due their heavier construction and requirements for tighter tolerances. Polymer construction may give the opportunity to eliminate much of this cost disadvantage, if Code issues with respect to flame and smoke can be handled.[3] Motor efficiency improvements may be a little more costly, but probably not a significant portion of the OEM sales price.

4.4 Standards Options

There are at least two feasible approaches to California state standards. One would build on the existing regulatory framework for furnaces, and use existing data sets. This is simple, but will leave untouched some of the potential savings, for two reasons. First, the furnace data do not precisely reflect electricity used by the fans. Second, it leaves heat pumps and other non-furnace air handler applications without explicit regulations.

Using Existing Data: We have evaluated the potential of using the existing public data on furnaces (GAMA 2003) to set standards for efficient air handlers in furnaces. The GAMA directory includes directly relevant data, including the annual fuel use (EF) for each model and its annual electricity use (Eae). AFUE gives seasonal (fuel) efficiency, which differentiates between condensing and non-condensing models. The directory does not include explicit air flow metrics, but the nomenclature (Directory Model Number) typically includes some measure of the size of the matching air conditioning evaporator See Appendix A for a fuller discussion. Inferences from model numbers are not precise, but can be used to check the robustness of measures considered for standards.

From separate analyses of non-condensing and condensing furnaces, we have concluded that one viable approach to standards is based on the fan energy ratio (FER):

$$FanEnergyRatio(FER) = \frac{E_{ae} \times H}{E_{ae} \times H + E_f}$$

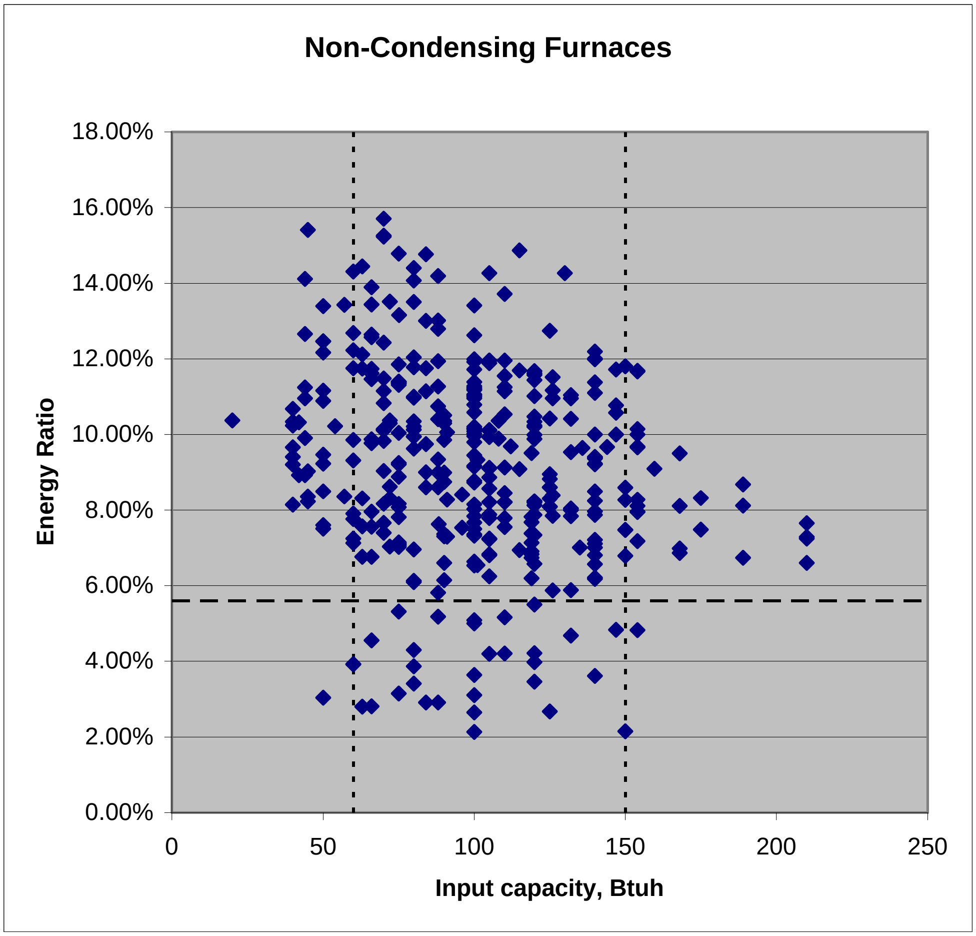
where: E_{ae} = Annual furnace electricity use (kWh)
E_f = Annual furnace energy use (Btu)
H = Heat Rate (Btu/kWh) = 10,329 Btu/kWh.

If this parameter is set at a level comparable to that which CEE and GAMA recognize as electrically efficient for condensing furnaces (as discussed in Section 6.2), it would establish a reasonable level for efficient air handlers for most furnaces. We recommend this approach, which is described in detail in Appendix A. Figure 1, the same as Figure A-7 in Appendix A, plots the FER against furnace (input) capacity. It suggests that a FER at the CEE/GAMA level (dotted

[3] J. Lutz, personal communication 2004, notes that this may be a concern.

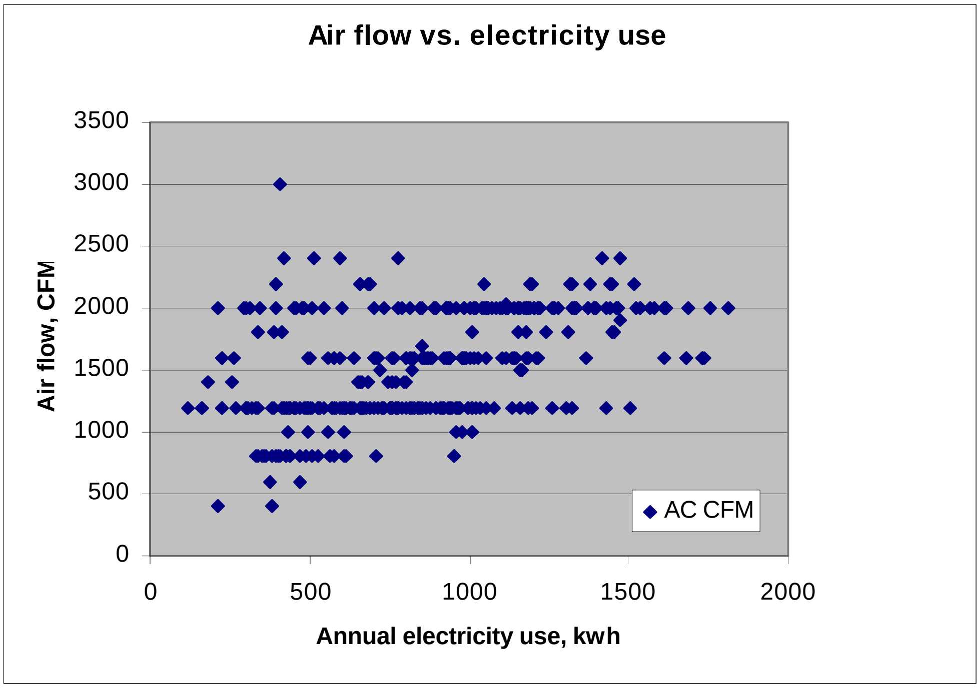
horizontal line) results in reasonable model availability for furnaces with input capacity between 60,000 and 150,000 Btu/hour. For smaller and large units, FER will also work, but a higher value is needed to permit a reasonable number of existing models to comply.

Figure 1. Fan Energy Ratio as a Function of Furnace Input Capacity.



To check this, we plotted measures of air flow and air flow efficiency against this metric. These measures, imputed from the model names (nomenclature), showed that there are reasonable numbers of electrically efficient furnaces designed for large air conditioners relative to their furnace capacity, *e.g.*, so-called “southern” models. For example, the second figure, Figure 2, (which is Figure A-4 in the Appendix) shows that imputed air flow varies enormously at the same electricity consumption.

Figure 2. Furnace Air Handler Electricity Use as a Function of Air Flow (CFM).



Alternative Approach: an alternative approach would treat the air handler of a furnace, heat pump, or CAC as another appliance for which standards are appropriate. The most straightforward option would require a minimum Watts/cfm efficiency for air handler fans. Given the lack of published manufacturer's data on the performance of furnace, heat pump, and air-conditioner fans today, a prudent first step would require the listing of furnace fan efficiency. Furnace fans could be tested according to ANSI/AMCA 210-99 (Laboratory Methods of Testing Fans for Aerodynamic Performance Rating). However, according to some experts there may be problems with using AMCA 210 on blowers with ECPM motors in the current test method.[4] A realistic external static pressure should be specified such as 0.5 i.w.c. Implementation of a listing requirement would put manufacturers on notice that furnace fan efficiency is recognized as an important issue in California.

4.5 Energy Savings

Improving motor efficiency through the use of ECPM motors is likely the simplest approach for manufacturers to pursue in the short term. According to manufacturer data collected by ACEEE (Sachs and Smith 2003), high speed "wire to shaft" motor efficiency for typical PSC motors range from 55-67%, or about 10-20 percentage points lower than ECPM motors (74-78%). Low speed ECPM efficiencies are approximately double that of PSC motors (70% vs. 34-39%).

Annual energy savings are estimated at 20% cooling savings and 50% heating savings. Annual furnace fan energy use in California is assumed to be 290 kWh for heating and 205 kWh for

[4] Apparently, these motors can be smart enough that when they are put in series with the relief fan in the air flow chamber the result is unstable operation. Lawrence Berkeley National Laboratory is trying to investigate this, but does not expect to have results for several months. If problems are found, there will have to be details developed on how to properly use AMCA 210 for this type of testing (Lutz, personal communication, 2004).

cooling (as discussed in section 4.1), resulting in an annual average California savings estimate of 160 kWh. These savings are very conservative relative to other national estimates of roughly 500 kWh heating and 200 kWh cooling (Sachs and Smith 2003). Estimates here do not recognize any additional savings due to improved blower design and airflow path through the air handler.

5 Economic Analysis

5.1 Incremental Cost

Table 3 provides DOE cost estimates of key fan efficiency improvement options developed as part of the current furnace standards work. Improved controls are not specifically addressed by DOE, although the ECPM is an adjustable flow device which can be programmed to run in variable speed mode or to deliver a fixed airflow quantity, among other modes.[5]

Table 3: DOE Estimated Retail Cost of Potential Fan Efficiency Improvements

Efficiency Measure	Cost
More efficient Permanent Split Capacitor (PSC) motor	$ 5
Electronically Commutated Permanent Magnet (ECPM) motor	$133
Switched Reluctance (SR) motor	$133
Improved Blower Efficiency (backward-curved blades)	$ 49

Source: DOE, 2002

Sachs and Smith (2003) estimated that improved motors, in a fully mature market, would add $25 - $45 OEM, but stress that this is higher than estimates for similar technologies in other applications. Sachs and Smith (2003) estimate *current* OEM *incremental* costs for ECPM motors currently as $80 - $90.

5.2 Design Life

ECPM motors have been commercially available for over ten years and have demonstrated good reliability. Projected service life for a forced air furnace is 20 years (APPL 2001b), resulting in a life cycle value of electricity of $1.533 per kWh saved annually (CEC 2001).

5.3 Life Cycle cost

Table 4 summarizes the net present value calculation based on the 20 year life of the furnace and fan motor.

Table 4: Analysis of Customer Net Benefit

Option	*Design Life (years)*	*Annual Energy Savings (kWh)*	*Present Value of Energy Savings*[*]	*Incremental Cost*	*Net Customer Present Value*[**]
ECPM	20	160	$245	$133	$112

*Present value of energy savings calculated using a Life Cycle Cost of $1.533/kWh (CEC 2001).
**Positive value indicates a reduced total cost of ownership over the life of the appliance

[5] J. Lutz (personal communication, 2004) suggests that some versions can also be programmed to operate in constant torque or speed modes as well.

6 Acceptance Issues

6.1 Infrastructure Issues

Alternative blower designs or cabinet geometries would have minimal impact on final cost, although operating efficiencies could be improved significantly. The use of ECPM motors however could have a number of infrastructure effects. Air handler manufacturers will be concerned that increased manufacturing costs will result in lower sales. Currently there are only two major manufacturers of ECPM motors for HVAC equipment, so an ECPM-based standard may allow them to have significant market power.[6] ECPM motors are also more complex and will require additional training and equipment for the repair and maintenance industry. On the other hand, recent advances in switched reluctance motors and their widespread use in some appliances suggest that these will begin to compete with ECM motors for fans, at potentially lower cost in high volume manufacturing (Sood and others, 1999). Both classes have similar issues and capabilities with respect to power quality. There are other variable speed motor technologies available as well, such as optically commutated motors that are in development. Their efficiency may not be quite as high as ECPM, but the cost will probably be lower (Lutz, personal communication, 2004).

6.2 Existing Standards

Since 1976, all gas furnaces sold in California have been required to meet specified minimum efficiencies. From 1976 until the passage of the National Appliance Energy Conservation Act of 1987 (NAECA), central gas furnace minimum seasonal efficiency[7] of 72 percent was required (CEC, 1983). With passage of NAECA, which superceded state standards, all furnaces sold were required to have an AFUE of at least 78%. However, AFUE does not include the effect of furnace electrical use as seasonal efficiency does, and therefore does not provide any indication of the efficiency of the furnace fan. The DOE furnace efficiency rule making for 2005 is currently just beginning, but could include a provision recognizing fan energy use. DOE's General Counsel has not interpreted the act favorably in this respect (McCabe 2003), but the pending federal energy bill explicitly authorizes consideration of furnace electricity use. At present, while the federal standards preempt state regulation of AFUE, it is unclear whether they preempt regulation of other aspects of furnace efficiency. Manufacturers believe that the federal AFUE standards preempt any state regulation of furnace efficiency (Mattingly 2003). We recommend that CEC Counsel review this issue. Furthermore, a CEC rulemaking on fan efficiency is likely to encourage DOE to more seriously consider fans in their furnace venue. Manufacturers have expressed a strong preference for federal regulation rather than state regulation, if furnace fans are regulated (Mattingly 2003).

Lessons from Market Transformation Programs: Oregon and Wisconsin offer incentives for condensing furnaces equipped with ECPM motors, as a prescriptive route to improved efficiency. Massachusetts utilities offer a performance-based incentive, based on models with a maximum electrical efficiency compared with fuel use. Working with CEE, GAMA has developed a comparable criterion based on the ratio of annual (site) electricity use to the sum of site electricity and gas use. Using this parameter, CEE and GAMA recognize electrically-efficient furnaces as those with a site electrical energy use to total site energy use ratio of 2.0% or less. For this CASE study, we have determined that a similar approach using source energy and California-specific heat rates will work for non-condensing furnaces. Specifically, at California heat rates of 10,329

[6] But, other manufacturers are poised to enter the US air handler market, as noted also by J. Lutz (personal communication, 2004).

[7] Heating seasonal efficiency ($Effy_{HS}$) is defined in ASHRAE Standard 103, Chapter 11 for all types of furnaces. It includes the effect of both gas and electricity use on overall efficiency.

Btu/kWh, the CEE/GAMA criterion is identical to a FER (as defined in section 4.4) of 5.64 or less. Appendix A establishes that there is a reasonable population of non-condensing furnaces with very high electrical efficiency at most furnace capacities ("southern" models). We conclude that there are no technical barriers to prevent adoption of a reasonable standards criterion for electrical efficiency of furnaces for implementation in California, although standards of this type would require a more relaxed parameter for the small fraction of very high and very low capacity models. As discussed in Appendix A, we recommend a maximum FER of 8.5 for units with a heating input capacity less than 60,000 Btu/hour and a maximum FER of 7.0 for units with a heating input capacity more than 150,000 Btu/hour. In order to give manufacturers time to upgrade non-complying models to meet this standard, we recommend that this standard take effect January 1, 2007 – three years from now and more than two years from when the CEC rulemaking is likely to be completed.

7 Recommendations

It is recommended that manufacturers be required to disclose air handling efficiency, so it can eventually be regulated under Title 20. Based on the current lack of published manufacturer's data, we propose that air handlers sold in California be required to be tested and listed based on ANSI/AMCA 210-99, *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating (AMCA 1999)*.[8] Explicit inclusion of fan energy in the federal standard should be advocated.

In the short run, California should adopt an interim air handler efficiency standard based on the ratio of (source) electrical to total energy use. The value 5.64 is roughly the same as the definition of efficient air handler by GAMA and CEE for condensing furnaces,[9] and will work for all but the smallest and largest furnaces. Thus we recommend a minimum Fan Energy Ratio (FER) of 5.64 for furnaces with an input capacity of 60,000-150,000 Btu/hour, 8.5 for furnaces with an input capacity of less than 60,000 Btu/hour, and 7.0 for furnaces with an input capacity of more than 150,000 Btu/hour.

Specifically, we recommend that the following definitions and tables be added to Title 20:

Central furnace air handler. The section of the furnace that includes the fan, blower, filter (usually), and housing, generally upstream of the burners and heat exchanger. In most California residential applications, the central air handler includes a cooling coil.

Annual furnace electric energy use (E_{ae}) = has the same meaning as in the DOE furnace efficiency test procedure.

$$FanEnergyRatio(FER) = \frac{E_{ae} \times H}{E_{ae} \times H + E_f}$$

were: E_{ae} = Annual furnace electricity use (kWh)
E_f = Annual furnace energy use (Btu)
H = Heat Rate (Btu/kWh) = 10,329 Btu/kWh.

[8] Also available as ANSI/ASHRAE 51-1999.
[9] The GAMA/CEE metric is based on site energy use (3412 Btu/kWh), while the metric used here is based on source energy, using the average heat rate for California, 10,329 Btu/kWh

The maximum fan energy ratio of a residential furnace sold for use in the state after January 1, 2007 shall meet the requirements in Table 5.

Table 5.
Maximum Fan Energy Ratio for Residential Furnaces

Furnace Input Heating Capacity (Btu/hour)	Maximum Fan Energy Ratio
Less than 60,000	8.50
60,000-150,000	5.64
More than 150,000	7.00

8 References

[AMCA] Air Movement and Control Association 1999. *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating.* Air Movement and Control Association, Arlington Heights, Il. www.amca.org.

[APPL] 2001: *Appliance*, **58**, 5, May 2001.

[APPL] 2001b: *Appliance*, **58**, 9, September 2001.

[APPL] 2001c: http://www.appliancemagazine.com/article.cfm?articleIndexID=1113 (December 2001).

[APPL] 2002: *Appliance*, **59**, 10, October 2002, p. 37.

[ANSI/ASHRAE] Standard 103-1993: Method of Testing for Annual Fuel Use Efficiency of Residential Central Furnaces and Boilers,

[CEC] 1983: California Energy Commission. 1983. *California's Appliance Standards: A Historical Review, Analysis, and Recommendations, Staff Report*. Sacramento, Calif.: California Energy Commission. (not obtained, but cited by others, esp. Kubo et al. 2001).

[CEC] 2000: California Energy Demand 2000, CEC, 2000.

[CEC 2002: Database of equipment at http://www.energy.ca.gov/appliances/appliance/dbf_files/ The fan file is "fur_dbf.zip".

[CEC] 2001. [lifecycle cost calculations for Title 20].

[CEC] 2002(a): calculations at:z:\standards\title20pg&e\furnacefan\cecdbffiles \fur_dbf_r3_atmos.xls\fur_dbf_atmos_only_shortQ139:T141.

[CEC] 2002(b): calculations at: z:\standards\title20pg&e\furnfacefan\cecdbffiles \fur_dbf_r4_noncond.xls\fur_r4_nocool_3phase_short\P773:R775

[CEC] 2002(c): calculations at: z:\standards\title20pg&e\furnacefan\cecdbffiles \fur_dbf_r5_cond.xls\fur_dbf_r5_short\P506:Q508.

[CMHC] 1992: Canadian Housing and Mortgage Corporation, *Barriers to the Use of Energy Efficient Residential Ventilating Devices, A Survey of Industry Opinion, and a Review of Strategies for Change*, 1992.

[CMHC] 1993: Canadian Housing and Mortgage Corporation, *Efficient and Effective Residential Air Handling Devices, Final Report*, 1993.

[DOE] U. S. Department of Energy 2001: Framework Document for Residential Furnaces and Boilers – Energy Conservation Standards Rulemaking, U.S. DOE, July 17, 2001. (Available online at "http://erendev.nrel.gov/buildings/codes_standards/notices/pdfs/furn_boiler_frame.pdf".

[DOE] 2002: Furnaces and Boilers Standards Rulemaking, Draft Report for Review, Engineering Analysis, Building Technology Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, September 19, 2002.

[DOE] 1997. "Energy Conservation Program for Consumer Products: Test Procedures for Furnaces/Boilers, Vented Home Heating Equipment, and Pool Heaters." Office of Conservation and Renewable Energy. *Federal Register* 62 (91): 26140-26165.

[EIA] 1997: *A Look at Residential Energy Consumption (Survey, RECS) in 1997*, Report DOE/EIA-0632(97), Energy Information Administration, 1997.

[ES] 1993: High-Efficiency Residential Blower Motor Replacements: Capturing a Lost Opportunity, Report TU-93-11, E-Source 1993.

[GAMA] 2002: GAMA Consumers' Directory of Certified Ratings, April 2002.

[GAMA] 2002(a): Calculations at: z:\standards\title20pg&e\furnacefan\gamafiles\gamafurnaces2.xls\k1278:o1280)

Gusdorf, J. M. Swinton, C. Simpson, E. Enchev, S. Hayden, and B. Castellan. 2003. Final Report on Effects of ECM Furnace Motors on Electricity and Gas Use: Results from the CCHT Research Facility and Projections. Natural Resources Canada

Kubo, Toru, Harvey Sachs, Steven Nadel, 2001, *Opportunities for New Appliance and Equipment Efficiency Standards*, ACEEE Report A016, September 2001.

Mattingly, Joe, GAMA. 2003. Personal Communication with Steven Nadel.

McCabe, M. DOE.. 2003. Personal Communication with Steven Nadel.

[PG&E] 1997: *Residential Energy Survey Report* (RAEUS), p. A1-1.

Phillips, Elbert. 1995. Blower Efficiency in Domestic Heating Systems. CEA 9202 U 921. Winnipeg, Manitoba: UNIES Ltd

Phillips, B. 1998. Impact of Blower Performance on Residential Forced-Air Heating System Performance. Transactions ASHRAE SF-98-02.

Pigg, S. 2003. Electricity Use by New Furnaces: A Wisconsin Field Study. Technical Report 230-1, Energy Center of Wisconsin, Madison, WI.

Sachs, Harvey M., Toru Kubo, Sandy Smith, Kalon Scott, 2002, *Residential HVAC Fans and Motors are Bigger Than Refrigerators*, ACEEE, Washington, DC.

Sachs, Harvey M., Sandy Smith, 2003, *Energy Savings from Efficient Furnace Air Handlers in Massachusetts*, ACEEE, Washington, DC.

Sood, P., R. Furmanek, J. Lloyd, P. Riola, and S. Randall. 1999. "Switched Reluctance Motor-Drive System for Washing Machines." http://www.gotoemerson.com.

Walker, I.S, M.D. Mingee and D.E. Brenner., 2003. Improving Air Handler Efficiency in Residential HVAC Applications. LBNL 53606. Lawrence Berkeley Laboratory, Berkeley, CA.

9 Appendix A

Objective:
This appendix describes efforts to develop air handler efficiency metrics from information in the GAMA Directory. The goal is to discover measures that easily and reliably differentiate electrically efficient gas furnaces from less efficient models, to serve as standards for electrically-efficient furnaces. We focused particular attention to non-condensing furnaces, testing the hypothesis that manufacturers may market relatively small non-condensing furnaces with relatively large fans to serve large cooling loads relative to heating loads in southern and southwestern applications.

Background:
Sachs & Smith (2003 and 2004) have established a reasonable metric for condensing furnaces, based on public data in the GAMA directory. Fundamentally, it looks at the ratio of annual electricity use (Eae) to input gas capacity (Btuh). GAMA and CEE have adopted a variant of this, defining electrically efficient furnaces as those whose *site* electrical energy consumption is no more than 2% of the annual site gas + electricity consumption. For non-condensing furnaces, there has been concern that some or many models would show a decoupling of gas use from electricity use, as "southern" models would be manufactured with larger fans relative to the furnace size, to support relatively large air conditioning evaporators.

We conclude that it is feasible to establish electrical efficiency metrics for non-condensing furnaces. The most straight-forward approach is similar to that for condensing furnaces, relying on the same formulation, except expressed in terms of source energy: Eae (Btu) divided by the sum of [Eae (in source Btu) + Ef][10], defined as the annual electricity use divided by the sum of the annual electricity consumption and annual gas consumption. Both parameters are published in the GAMA directory. There is, however, one significant difference: A single parameter value for all capacities will not suffice for non-condensing furnaces. We propose that California adopt a version of the criterion developed by GAMA and adopted by CEE for condensing furnaces, with some changes: (1) Convert the basis from site electricity to source electricity, which yields a parameter for electrical efficiency of 5.64% of total source energy, based on California Heat Rate of 10,329 Btu/kWh.[11] (2) for furnaces > 150,000 Btuh input, this criterion should be relaxed to 7%, and for furnaces <60,000 Btuh input, this criterion should be relaxed to 8.5% as the distribution of electrical efficiencies in existing models suggests technical challenges in achieving the 5.6% level with these large and small units.

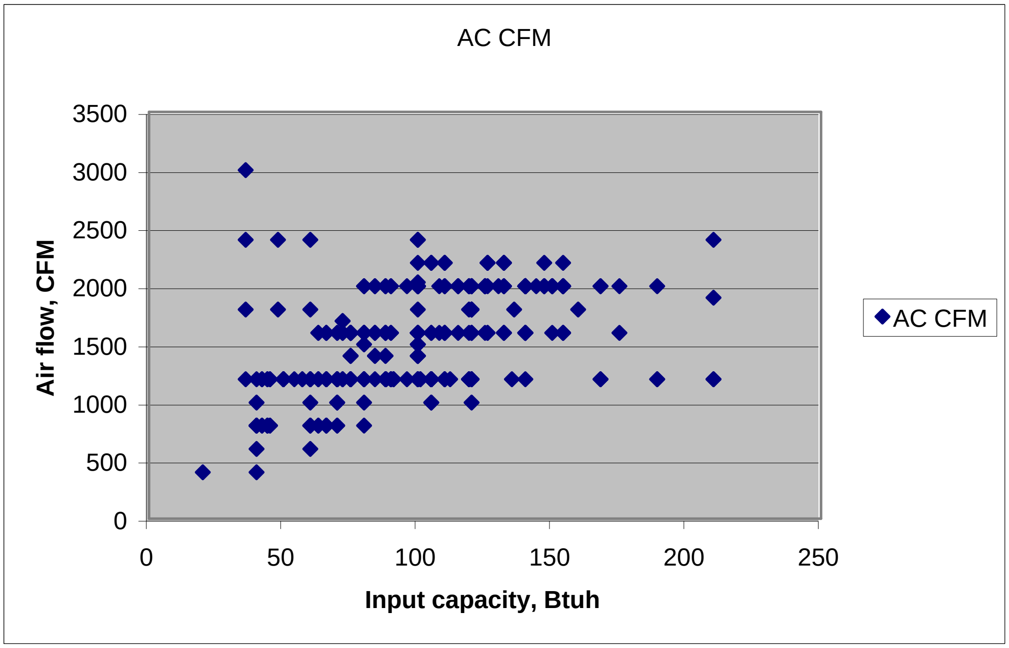
Methods:
ACEEE began with a DEG data set derived from the GAMA directory of May, 2003. DEG removed all duplicate listings with identical performance specifications but different model or brand names, reducing the original 31,529 rows to 1328 non-weatherized models. After removing some outliers with anomalous data and models for which we could not impute air flow (see below), ACEEE split the data into a set with about 380 non-condensing models and another one

[10] Specifically, we used a California-specific heat rate, 10,329 Btu/kWh.
[11] We use source energy because it accounts for all of the energy used to power the air handler – the energy used on site as well as the energy losses at the power plant that are necessary to generate a kWh of electricity. Use of site energy ignores the efficiency of electricity production and thus tends to trivialize the energy used by the air handler.

with about 400 condensing models. In this work, we used both the explicit data in the GAMA directory (capacity, AFUE, electrical and gas annual consumption (Eae and Ef, respectively), and implicit data drawn from furnace model names.

Furnace model names (Directory Model Names, nomenclature) are alphanumeric strings that include the information that contractors need to specify the correct unit for each application. These include indicators of furnace capacity, efficiency, and cabinet configuration (upflow, downflow, horizontal). In addition, most include one of three different indications of the capacity of the evaporator designed to match the furnace, since most furnaces also serve as the cooling air handler. (1) The matched evaporator capacity may be indicated by a digit (3, 4, 5, sometimes "3/4" or "4/5") or a single letter (C, D, E) that represents the evaporator size, in refrigeration tons, at 12,000 Btu/ton. (2) In a common variation, some brands indicate the size as KBtu/h cooling capacity (36, 48, 60 as 3, 4, and 5 tons, respectively). (3) Another nomenclature class directly indicates maximum air flow, typically in hundreds of CFM, either with two-digit numbers or an alphabetic code. In addition, at least one brand explicitly gives the physical dimensions of the air handler fan, and its output range. Nomenclature varies enormously among brands, and sometimes by product line within brands. The position of the identifying characters varies, too, even in some cases for a given manufacturer. Thus, to impute air flow or air conditioning capacity, we needed to sort the data by model nomenclature within brands, and examine each listing for compliance with rules for conversion to air flow or air conditioning capacity that were provided to us by manufacturers, contractors, and other furnace experts. There may be conversion errors from this effort, as not all nomenclature is unambiguous. Also, our approach has been exploratory and graphics-based. Statistical significance has not been estimated, for two reasons. First, we have done some data selection (e.g., removal of outliers substantially displaced from all other models, and removal of models for which we were unable to infer air handler capacity). Second, the data, particularly air handler capacity, are not smoothly distributed. Air handler capacity clusters strongly in discrete groups (800, 1200, 1600, 2000 cfm, corresponding to 2, 3, 4, and 5 ton evaporators). This deviates from the assumptions for parametric statistics, and gives trend lines that are artifacts in some graphs. This is shown in Figure A-1, which plots air flow versus furnace input capacity for the non-condensing furnaces. This clearly illustrates the clustering of air flows at air conditioning size breaks most common in the marketplace.

Figure A-1: Air flow (cfm) versus input capacity for all non-condensing furnaces.



Note that "Air flow, CFM" was imputed from nomenclature, most of which does not explicitly give air flow, but rather some proxy such as matched evaporator size. "Air flow, CFM" has been used only to check the effectiveness of the criterion described above. Thus, we turned to the major thrust, investigating electricity consumption as a function of furnace capacity. We started with a single product line with explicit air flow data (Figure A-2), and extended it to the larger population of non-condensing models (Figure A-3).

Figure A-2. Annual Electricity vs. furnace size, one manufacturer's non-condensing furnaces. There is a strong suggestion of a range of more efficient models in the lower right of the graph. However, the nomenclature for this brand is ambiguous with respect to variable speed fans, so we expect that some of the higher consumption models are actually efficient "southern" models with larger fans.

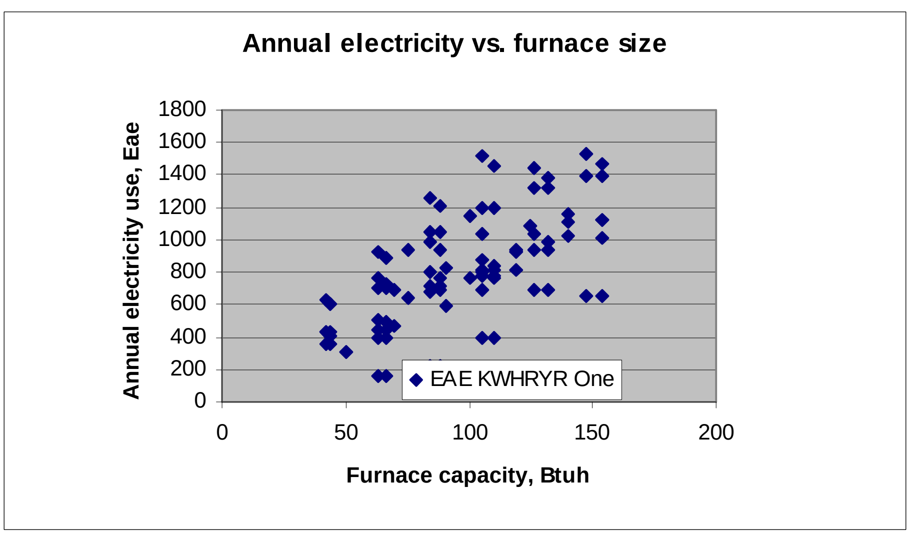


Figure A-3 is similar, but presents data from the whole set of non-condensing models. As in Figure A-2, there appears to be a gap in the graph of annual electricity use as a function of furnace capacity. This region (lower right of graph) has models with relatively low electricity consumption. However, it does not show whether some of the higher-electricity use models have larger air handlers to meet "southern" loads.

Figure A-3. Annual Electricity vs. furnace size, for all non-condensing furnaces.

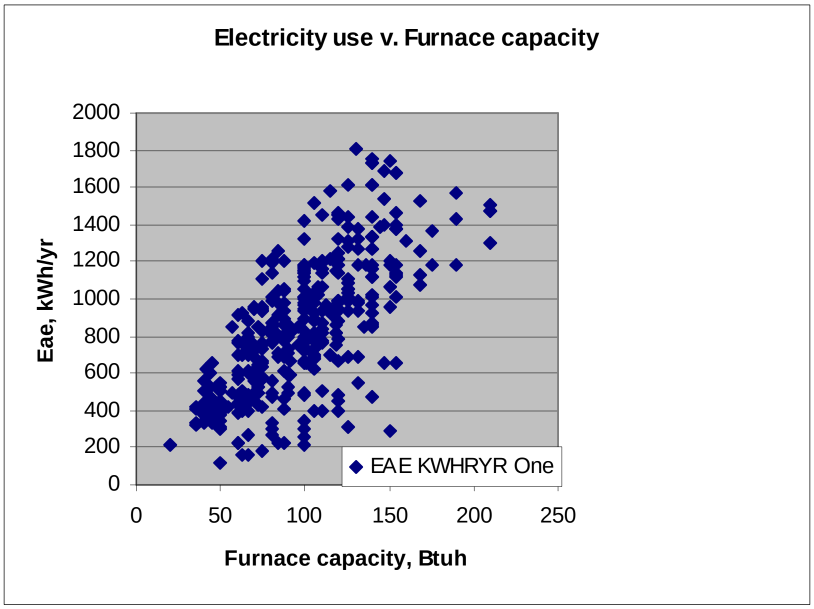
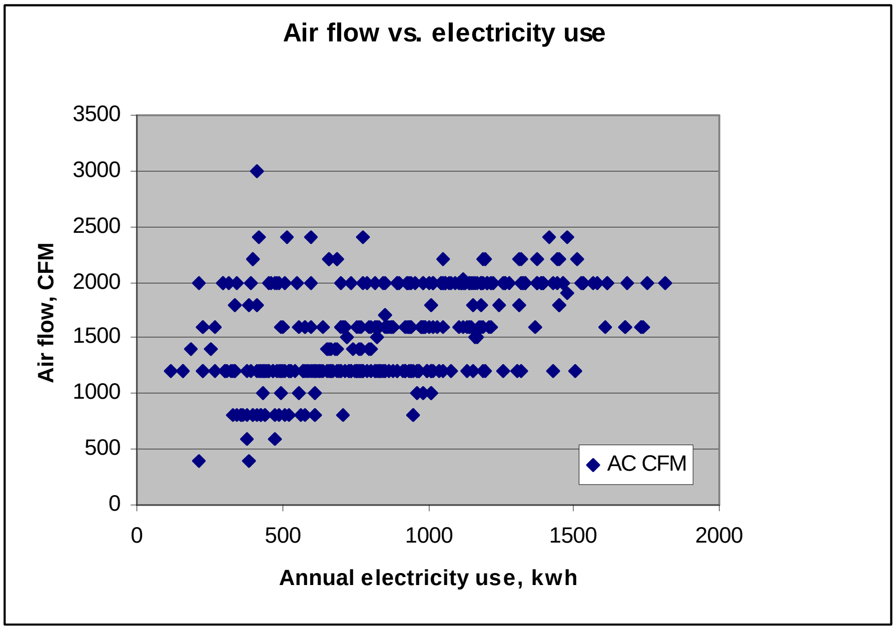


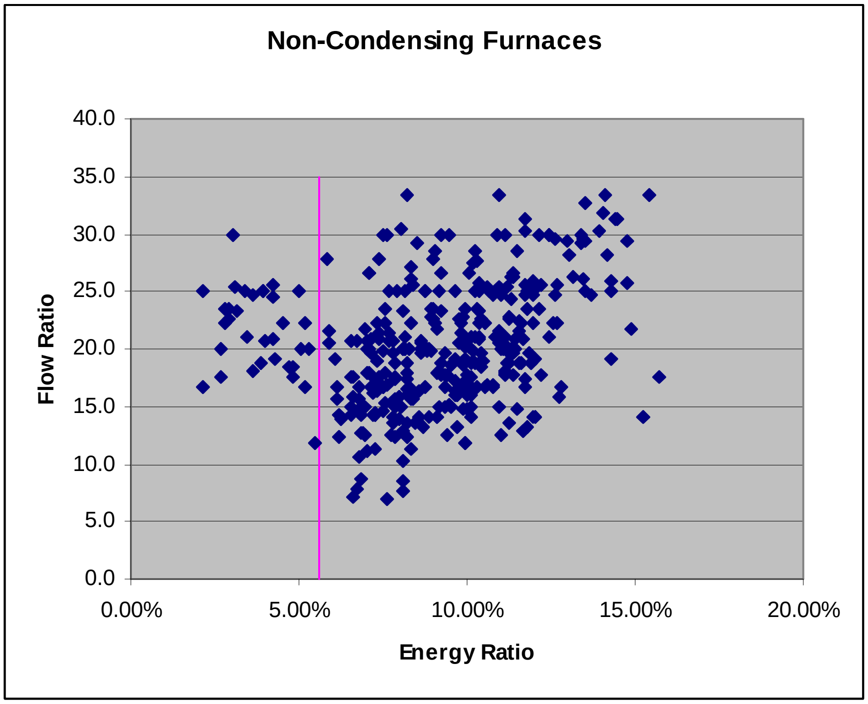
Figure A-4 presents an alternative view of the data, plotting (imputed) air flow against annual electricity use. The clustering of data at discrete air flow levels is quite prominent, but the more important lesson is in the scatter of air flow at any given value of Eae, electrical consumption. Typically, there is at least a 3:1 ratio between the larger air flows and the smaller ones at any given electricity use. This indicates that high efficiency can be combined with low electricity use. For example, a significant number of 4-ton (2000 cfm) models use less than 500 kWh/year.

Figure A-4. Annual electricity use (Eae) vs. air flow (CFM) for all non-condensing furnaces.



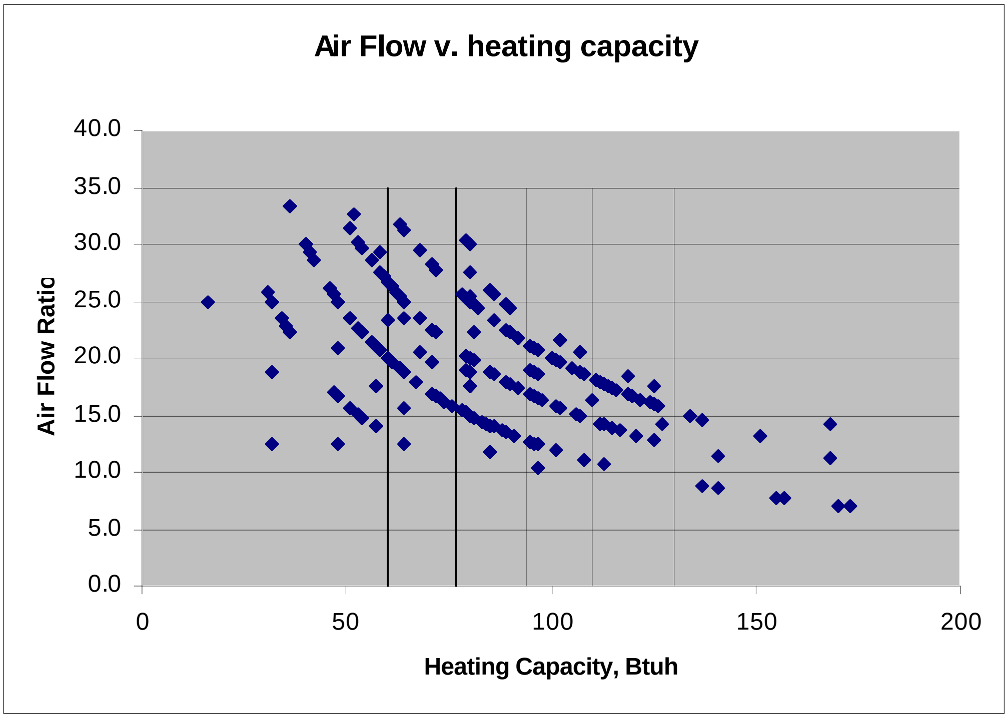
We then examined computed ratios (air flow/heating capacity; and source-based electricity use/total energy use), which attempts to normalize flow and energy by removing the influence of capacity. High flow ratios indicate relatively large matched evaporators for the furnace size (which suggests models designed for southern applications), while low energy ratios indicate electrically efficient furnaces. Thus, units with both characteristics are electrically-efficient Southern models (Figure A-5).

Figure A-5. This shows 380 non-condensing models (12 models with flow ratios > 35 were excluded to expand the Y-axis range). A flow ratio of 20 would characterize a 100 kBtu furnace with a 2000 cfm blower, 60kBtu furnace with 1200 CFM fan, etc. The vertical line represents the average energy ratio (based on California heat rate of 10,329 Btu/kWh) for furnaces that would be considered electrically efficient with the GAMA 2% criterion converted to source energy.



The relatively large number of models in the upper quadrant left of the 5.64% line and above flow ratio = 20 suggests that there are electrically-efficient non-condensing furnaces. But, it does not address the question of their distribution by furnace capacity. To address this issue, we plotted the air flow ratio (CFM divided by furnace heating capacity) against heating capacity. The bunching of air flow and imputed air flow values at ton and half-ton sizes in Figure A-6 emphasizes the visual trends toward lower air flow efficiency with increasing size, as discussed above.

Figure A-6. Air flow ratio versus heating capacity. Air flow ratios (Cfm/furnace output, Btuh) decrease with increasing size, suggesting that size-dependent criteria may be required rather than a single parameter value. Vertical lines represent size breaks at 60, 77, 94, 111, and 130 kBtu/h input capacity.

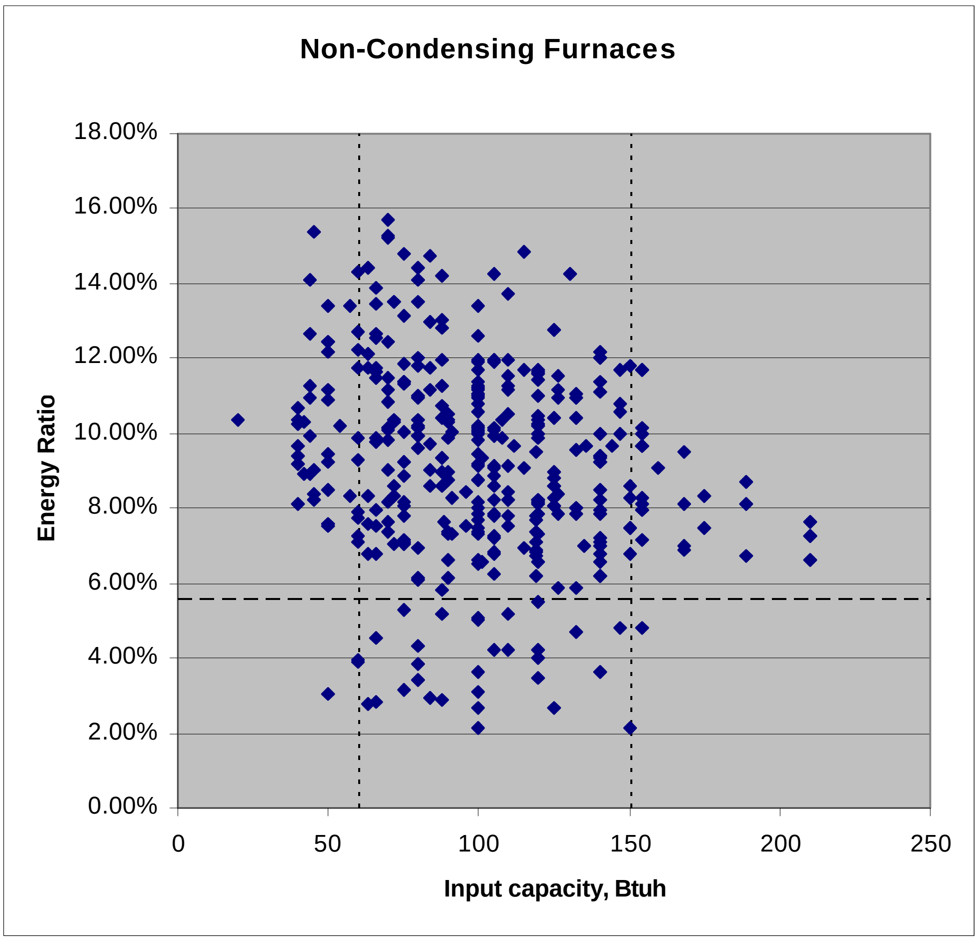


For standards-setting, the drawback of the approach of Figure A-6 is that the Y axis presents imputed values rather than parameters disclosed in the GAMA directory. However, it clearly suggests that air flow's proxy, annual electricity use (Eae) might be useful, if we use both Eae and furnace capacity, selecting limits on Eae by furnace capacity class. This will work even for "southern" models with large air conditioning capacity and high air flows relative to the furnace capacity, because we established in Figure A-5 that there are large numbers of electrically efficient furnaces (energy ratio < 5.65%) with high air flow ratios, which mark "southern" models.

Thus, it only remains to establish appropriate Eae limits for each capacity class. Figure A-7 plots the Energy Ratio against furnace input capacity. Values below the horizontal dashed line are electrically-efficient by the CEE/GAMA criterion for condensing furnaces. For capacities below 60k Btuh output or above 150 kBtuh output, there are few electrically-efficient non-condensing models available now.

For the smallest and largest furnaces, two approaches are available for standards. The first is to ignore current market availability, if a standard would not take effect before January 2006 or 2007 and therefore provide manufacturers time to develop complying models. For example, Figure A-6 suggests that small models can have very high flow ratios, and Figure A-5 suggests that efficient models can be produced with high flow ratios, so it should be feasible to bring complying models to market in a timely manner. However, this conclusion is subject to some uncertainty and therefore, a second approach using a relaxed criterion, should be considered for the largest and smallest capacities.[12] Although capacity-weighted sales data have not been found for California, we believe that the market share of such units is small, because of generally mild climates in the State. By number of models offered, 34 (9%) have input capacities of 150 kBtuh or larger. Moving the maximum FER from 5.6% to 7% for these units should suffice, since 20.5% of existing models would qualify. At 8%, 16 models (47%) would qualify already. Similarly, there are 47 model groups with input capacity no larger than 60,000 Btuh. Of these, a maximum FER of 8.5 would include 14 (30%) of the model groups, but none smaller than 45,000 Btuh input.[13] Alternatively, at FER 8.0, 9 groups qualify (19%).

Figure A-7. Furnace Energy Ratio vs. Input Capacity. Energy Ratio is the Annual electricity use (Eae) divided by the total (source) electricity + fuel use. Dashed horizontal line at 5.6% corresponds to CEE/GAMA limit for condensing furnaces, converted to source energy with California heat rate. Vertical dot-dashed lines at 60 kBtuh and 150 kBtuh draw attention to the outer portions of the chart, where there are few or no non-condensing models with high electrical efficiency/low energy ratio.



[12] E.g, with 5.6% as a threshold, only 2 of 34 models (6%) above 150,000 Btuh would qualify, and both of those are at the smaller end of these sizes (<155 kBtuh).
[13] There are 16 model groups smaller than 45 kBtuh, but of these only one is smaller than 40 kBtuh. Sheet "380 model data set.xls".

Discussion and Conclusions:

1. For non-condensing furnaces, heating capacity by itself is a poor predictor of electricity consumption. That is, a given furnace capacity from a typical manufacturer will include models with very different air handling efficiencies (Figure A-4). 2:1 air handler capacity variations within size classes are common. This suggests that manufacturers do offer "southern" models with higher air flow relative to furnace size for use in regions where larger evaporators are required.

2. In general, higher air flows (as inferred from the nomenclature) are associated with higher values of Eae, the annual furnace electricity metric reported in the GAMA directory (Figure A-4). However, the electricity metric is associated with both furnace size (Conclusion 1) and fan technology. Thus, all three parameters (air flow, furnace size, and fan technology/efficiency must be considered to develop an appropriate performance metric.

3. A source-based ratio of annual electrical energy use to electrical plus gas use, provides a reasonable basis for consideration as a standard, if relaxed somewhat for the smallest and largest equipment. This was confirmed by examining the variation of imputed air flow to furnace capacity, which shows that models with high air flow ratio were fairly common in most capacity brackets. As expected, parallel experiments with the set of about 400 condensing furnaces also support the idea that establishing a combination of flow ratio and energy ratio can serve to identify electrically efficient condensing furnaces.

References for Appendix A

GAMA, 2003. Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment. May, 2003. http://www.gamanet.org/consumer/consumer.htm

Sachs, H. M. and S. Smith, 2003. Saving Energy with Efficient Residential Furnace Air Handlers: A Status Report and Program Recommendations. ACEEE Report Number A033. American Council for an Energy-Efficient Economy, Washington DC

Sachs, H. M., and S. Smith, 2004. How Much Energy Could Residential Furnace Air Handlers Save? ASHRAE Transactions (Anaheim, January, 2004).